Modeling Twisted Coronal Loops: AR 10938

Leon Golub, Alexander J. Engell, Adriaan A. van Ballegooijen, Kelly E. Korreck, and Katharine K. Reeves

Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138, USA

Abstract. When modeling coronal loops by calculating the potential field from magnetograms it is often found that field lines highlighted of the potential field do not match the coronal loops observed in the data. To rectify this situation, we construct a non-potential field in which helical “twisted” currents with prescribed radii are inserted along certain potential field lines. We then relax the magnetic field to a non-linear force-free field (NLFFF) using magneto-frictional relaxation. In doing so, we find that we are able to approach a geometrical match between the field lines and the coronal loops observed in AR 10938 on January 18, 2007.

1. Introduction

Many active regions show geometrical inconsistencies between potential field models and observed coronal loops (Schrijver et al. 2005) which often takes the form of a shearing of the observed structures compared to the calculated field. The shearing of such coronal loops is more commonly observed in wavelengths that image higher temperatures in the corona. The X-Ray Telescope (XRT) on Hinode frequently observes highly sheared loops and so does the TRACE 284 Å filter to some degree. Distinct features such as sigmoids are extreme cases of a highly sheared corona (Canfield et al. 1999). Such features have been noted to be associated with the sources of flares and are often observed with both Yohkoh SXT and Hinode XRT.

Not all ARs have sigmoidal structure and many ARs show more moderate deviations from the potential fields. This paper describes a new technique that models the moderately sheared magnetic fields within the corona.

2. Method

We examine an Al-poly image taken by XRT at 04:00 UT January 18, 2007 of AR 10938, and found that several distinct coronal loops are observable, as shown in the left image of Figure 1. We overlay the potential field calculated from an MDI magnetogram on top of the XRT image in the right panel of Figure 1, and we observe that there are deviations between the potential field and loops in the image. Therefore we construct a non-linear force-free field (NLFFF) model to match several distinct field lines observed in XRT.

The NLFFF is constructed as follows. The magnetic field $\mathbf{B}$ is described in terms of the vector potential $\mathbf{A}$. First, a potential field is constructed. Then
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electric currents are inserted into the model by modifying the vector potential by an amount $\Delta \mathbf{A}$ parallel to $\mathbf{B}$. This modification is made along one or more channels parallel to the field lines with radius $R$ varying along the channel ($R \propto 1/\sqrt{B}$). The magnitude of $\Delta \mathbf{A}$ is specified in terms of the shear angle ($\theta$) of the modified field relative to the potential field. The maximum radius ($R_{\text{max}}$) and twist angle ($\theta$) can be manually selected for each channel. The sign of the twist angle chosen ($\pm \theta$) will determine helical orientation; either left helical for $\theta < 0$ or right helical for $\theta > 0$, and current ($J$) direction. The resulting non-potential field is not in equilibrium. Because of this, we apply magneto-frictional relaxation (Bobra et al. 2008) to drive the magnetic field to a NLFFF state. To achieve this state the vector potential is evolved according to the magnetic induction equation:

$$\frac{\partial \mathbf{A}}{\partial t} = \mathbf{v} \times \mathbf{B} + \left( \frac{\mathbf{B}}{B^2} \right) \nabla \cdot (\eta_4 B^2 \nabla \alpha),$$

where $\alpha = \mathbf{B} \cdot (\nabla \times \mathbf{B})/B^2$, $\eta_4$ is the magnetic hyper-diffusivity and $\mathbf{v}$ is the plasma velocity given by

$$\mathbf{v} = f \mathbf{J} \times \mathbf{B}/B^2$$

with $\mathbf{J} = \nabla \times \mathbf{B}$ and $f$ as the coefficient of the magneto-friction. This produces magnetic fields with field-aligned electric currents after 20000 iterations. (For details, see Bobra et al. 2008).

We attempt to closely match XRTs coronal loop observations. We constructed a series of models with different radii and twist angles for each respective current channel. In all the models the radii ranged between .01 and .09 solar radii and the twist angle between -30 and 50 degrees. We searched for the model that best fits the observed loops.

The movies, especially using TRACE data, show that loops continually evolve, appear, disappear, and/or reappear. We therefore refer to images over a period of time to infer coronal loop positioning, which helps to constrain models. Although the fit is not unique, the model provides an estimate of the 3D shape of the observed loops and the magnetic field strength as function of position along the loops.

3. Results

For our best-fit model we inject currents along four field lines, or channels, parallel to the potential field. The best-fit model has two channels with $\theta > 0$ and the other two channels with $\theta < 0$.

Figure 2 shows the best-fit model before and after magneto-frictional relaxation. Note that the final model presents a reasonable fit to the lines drawn on the left image in Figure 1. Despite an exhaustive parameter search to arrive at our best-fit model we were unable to match all observable loops. The model is not entirely unique; some of XRT’s observed loops may be reproduced with an opposite sign value for $\theta$. 
Figure 1. XRT observations of sheared coronal loops in AR 10938 on January 18, 2007. Both panels show the same XRT image taken in the Al-poly filter. Selected loops that were used in NLFFF modeling are indicated by thin lines in the left panel. In the right panel, contours of the photospheric magnetic field and field lines of the potential field are overlaid on the XRT image. Comparing the two panels it is obvious that the potential field does not match the observed coronal loops.

Figure 2. Non-linear force free field (NLFFF) model of AR 10938. The two panels show selected magnetic field lines before (left) and after (right) magneto-frictional relaxation, overlaid on the XRT image. The right image represents the best fit to the observed XRT loops shown in Figure 1 (left).

4. Discussion and Further Work

Here we have developed a technique for modeling sheared coronal loops in active regions. The advantage of the method is that it uses XRT observations which are sensitive to higher temperature plasmas in active regions. Another method has been developed by Aschwanden et al. (2008) using STEREO observations in
lower temperature spectral lines. In the future, we hope to combine these two methods. This study will help provide insight to how accurate our model is and if it is unique to the observed data. Specifically, we can compare our modeled 3D twisted field lines to triangulated 3D coronal loops from STEREO data. This procedure helps resolve the geometrical relations between the observed loops and the modeled twisted field lines, for example, whether one loop is on top or lying beneath another one. Thus, if we have modeled a field line below another and the triangulated STEREO loops show the opposite relation, we know our model is incorrect for those two particular field lines. Such observationally constrained models of the coronal magnetic field will be very useful for understanding coronal heating and thermodynamic structure of coronal loops. Through this modeling, it is our goal to closely compare theoretical models of coronal heating to direct observations.

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References

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